



I. Background

This is the fifth quarterly report of progress on the research program to study ice forces against arctic offshore structures. The first 12 months of this study were during the interval December 1, 1981 to December 1, 1982, under Contract No. DACA 89-82-K-0001. Because of a delay related to contracting details, the interval December 1, 1982 to March 1, 1983, was a time during which there was no contact in effect; a new contract, Contract No. DACA 89-82-K-0004, was started on March 1, 1983, and continues until March 1, 1984, representing the continuation of this research program. Thus this is the fifth quarterly report for the research program, and is also the first quarterly report under the new contract no. DACA 89-82-K-0004. This report covers the interval March 1, 1983 to June 1, 1983.

The objective of this research program is to provide information on the lateral forces exerted upon artificial islands and offshore structures by the moving sea ice. This is the major factor governing the design of new and robust offshore facilities for petroleum production in the Beaufort, Chukchi, and Bering Seas, a frontier oil province which includes some 262 million acres with a risked mean oil equivalent of 30.8 billion barrels.

The approach which has been planned is to measure the internal ice stress at relatively large distances from such islands, to measure the ice displacement simultaneously, and to determine the effective island width during all ridgebuilding events. These events, which fracture the ice adjacent to the islands and structures, represent those time intervals when maximum total forces may be exerted on such man-made structures. They represent intervals of extreme lateral force which can be used to develop the design conditions for the island or structure. Although very local ice rideup events may disturb the gravel beaches or rock slopes of artificial islands, this can be repaired. The more significant issue has been whether the lateral resistance to movement of the entire artificial island or offshore structure is sufficient to withstand the maximum total force exerted by the moving, fracturing ice. Allowance must be made in the design for the thickest ice and the highest velocity of ice movement expected during the

operation life of a production facility. A detailed discussion of then-current practice in such designs was given in the first quarterly report.

In the second quarterly report, the completion and calibration of the electronic data telemetry system was described. The theory necessary for converting gauge output information into principal stress magnitude and direction was also developed during the second quarter, and detailed in that report. The calibration program for gauges frozen into ice blocks was begun, and the experimental determination of the stress concentration factor $\alpha(\theta)$ for uniaxial stiff gauges was begun.

In the third quarterly report, the modification of the electronic telemetry system to accommodate an additional strain sensor was mentioned, and the improved reconfiguration of that system was described. A major technical contribution in the third quarterly report was the paper "A Surface Integral Method for Calculating Ice Loads on Offshore Structures from In-Situ Measurements", by Dr. J.B. Johnson.

As described in the fourth quarterly report, the complete electronic system checkout took place, wind generators and a logic network for sequential charging of on-site batteries were acquired, fabricated, and checked. The same report mentions the design and fabrication of the ice movement system, and the digital shaft encoder coupling which was designed to provide a measurement of tidal and lateral movements to a precision of 0.149 inches.

During the interval December 1, 1982 to March 1, 1983, a great deal of final field equipment preparation took place, although the program was not funded. Hence, on March 1, 1983, when continuation funding commenced, field deployment was rapid.

II. Experimental Program

On March 5, 1983, five days after the new contract started, the equipment deployment began. During January 1983, negotiations with top

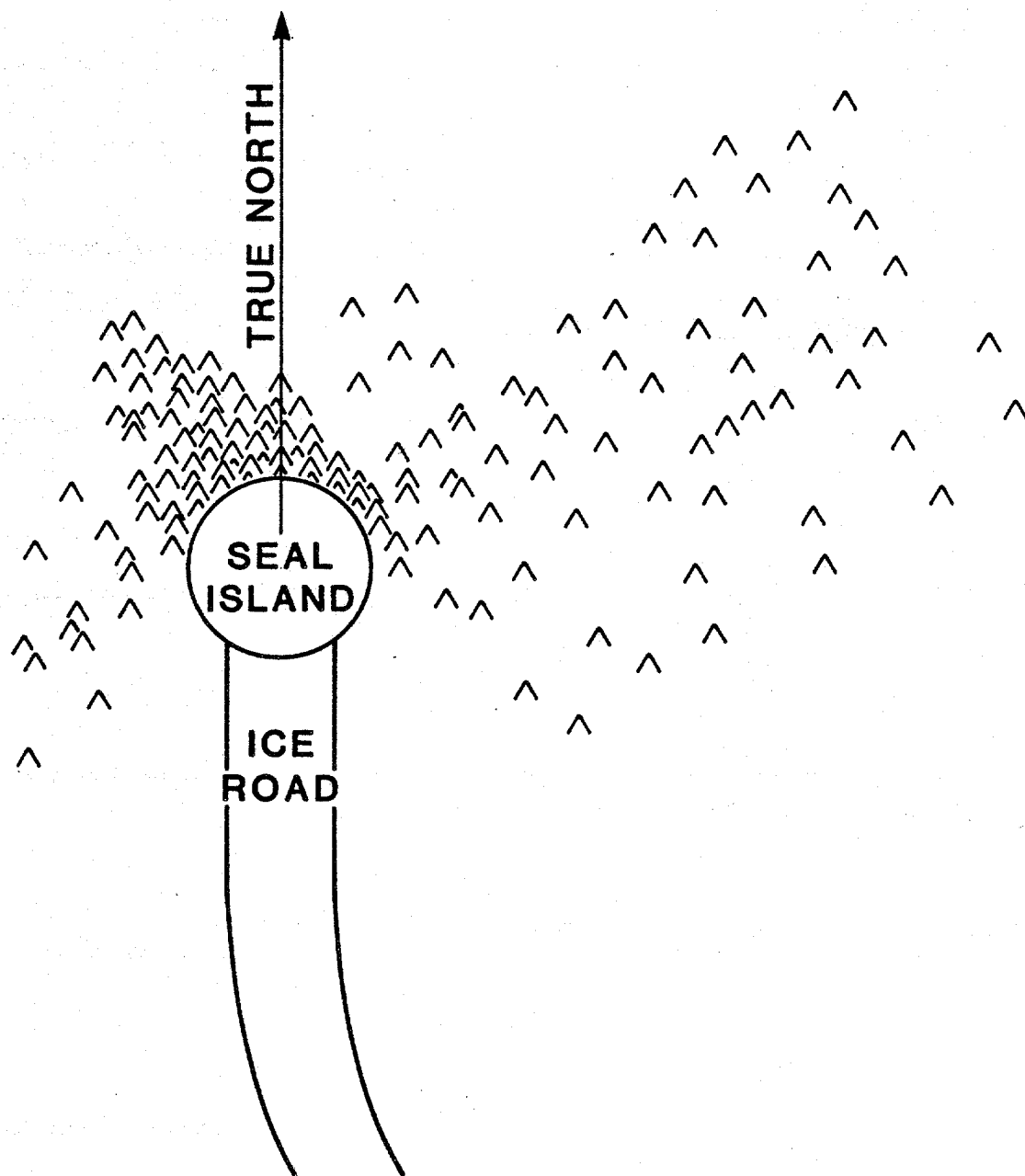
management of Dome Petroleum Ltd. were not successful in obtaining permission to deploy the experiment around their Uviluk site. That site, in 34 meters water depth, consisted of a sand berm built up underwater by dredging, upon which a converted and strengthened half of a supertanker was emplaced by ballasting it down on the berm. It was originally thought that this would be an excellent site for the deployment because of the virtually continual movement of ice around it. Ice movement velocities during winter were typically 1-2 kilometers per day, and from discussion with Dome scientists it was clear that the Uviluk (SSDC) site was in the shear zone. Although ice activity was great, and ice ridges and rubble were constantly being created, the ice rubble was generally reported as clearing around the SSDC structure, not accumulating rubble on the upstream side and not producing a grounded rubble pile upstream from the structure. It should be noted that this was the first steel structure affixed to the seafloor in such deep water and subjected to continuous moving ice. As such, one might expect to learn several things quantitatively from it. For example, the water depth was so great that appreciable grounded rubble did not form upstream. Furthermore, the ice in the shear zone which did move past the SSDC was annual ice from recently refrozen leads, of highly-variable thickness from day to day, ranging from 10 cm to 1 meter or so, but very frequently in the range 20 cm to 40 cm. That ice is relatively new, warm, and weak.

In retrospect, it is fortunate that the system which we wished to deploy was not emplaced around the SSDC for several reasons: (a) we needed a minimum of 30 cm of ice thickness in order to properly embed the stress and strain gauges; this was not always available at the SSDC; (b) our ice movement equipment was designed for total movement of the ice sheet of some 130 meters before resetting the ice movement station reference anchor points; that would have only allowed ice movement data for a few hours at the SSDC; (c) a freeze-in transient time of a few hours is required for the installation of our in-situ gauges, during which the stations would have moved considerably; (d) the rapid ice movement rate at the SSDC meant that a choice of upstream deployment 1-2 km away would have given a data-gathering period of only 1-2 days before the equipment would have been destroyed by ice fracture; (e) the telemetry would have to have been modified to be

omni-directional to allow for great movements; (f) rapid, helicopter-assisted deployment would have been essential; (g) no time would have been available for on-ice readjustments or contingencies. Moreover, the Canadian governmental agency permissions required to do research work in Canada, to import and to operate electronic equipment, proved to be more detailed than in earlier experiments of past years. Hence, it was decided to deploy at the original Seal Island site near Prudhoe Bay, after briefly considering Tarsuit Island, owned by Gulf Canada in MacKenzie Bay. Tarsuit was the site of a very active Canadian industry research program in 1982-83, including strainmeters beyond the ice rubble, ice pressure sensors, movement stations, and pressure-sensing panels on the Tarsuit caisson itself. Time and logistics did not allow our participation at Tarsuit; it was perceived to be at the edge of the zone of shorefast ice, just as was Seal Island in early winter. Deployment at Seal Island was executed in March 1983 with the outstanding cooperation of Shell Oil Company personnel.

An installation team consisting of W. Sackinger, J. Johnson, W. Zito, D. Solie, and M. Sturm, completed the physical installation by March 11, 1983.

Inspection of the Seal Island site revealed that ice rubble had formed on the northwest side of the gravel island earlier in the winter, when the ice was 20 cm to 40 cm in thickness, as illustrated schematically in Figure 1. A low (lm) ridge of sea ice rubble also extended from the island towards the northeast, as shown in the view of the island site from station S3 (Figure 2). It was subsequently determined, from analysis of satellite imagery (Figures 3,4) that the ridge passed through Seal Island and continued in an arc to the barrier islands to the southwest, as well as to Reindeer Island to the northeast. This suggests that the presence of Seal Island defined the edge of the shorefast ice earlier in the winter, and in fact may have extended it beyond its usual location. One might expect that analyses of previous year's satellite imagery could help clarify this issue, but the satellites have been routinely turned off in December and January for that region for many years, and only with the new University of Alaska "Quick Look" satellite capability has it been possible to get mid-winter images from Prudhoe Bay this year. From the satellite imagery, it is clear that the



**Figure 1. Schematic sketch of ice ridging
around Seal Island, March 1983.**

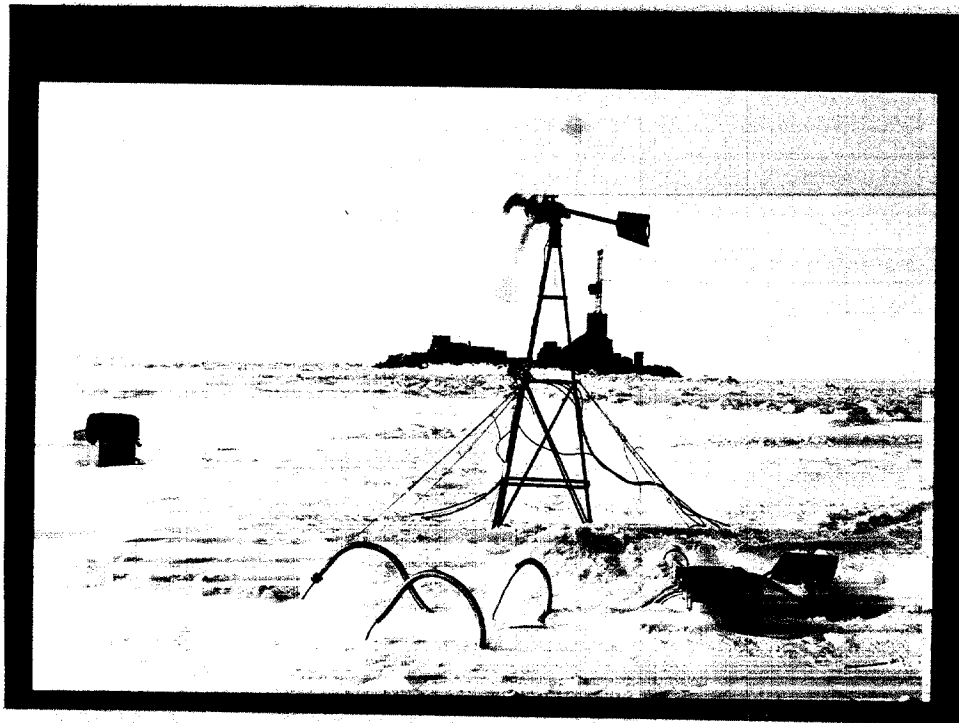
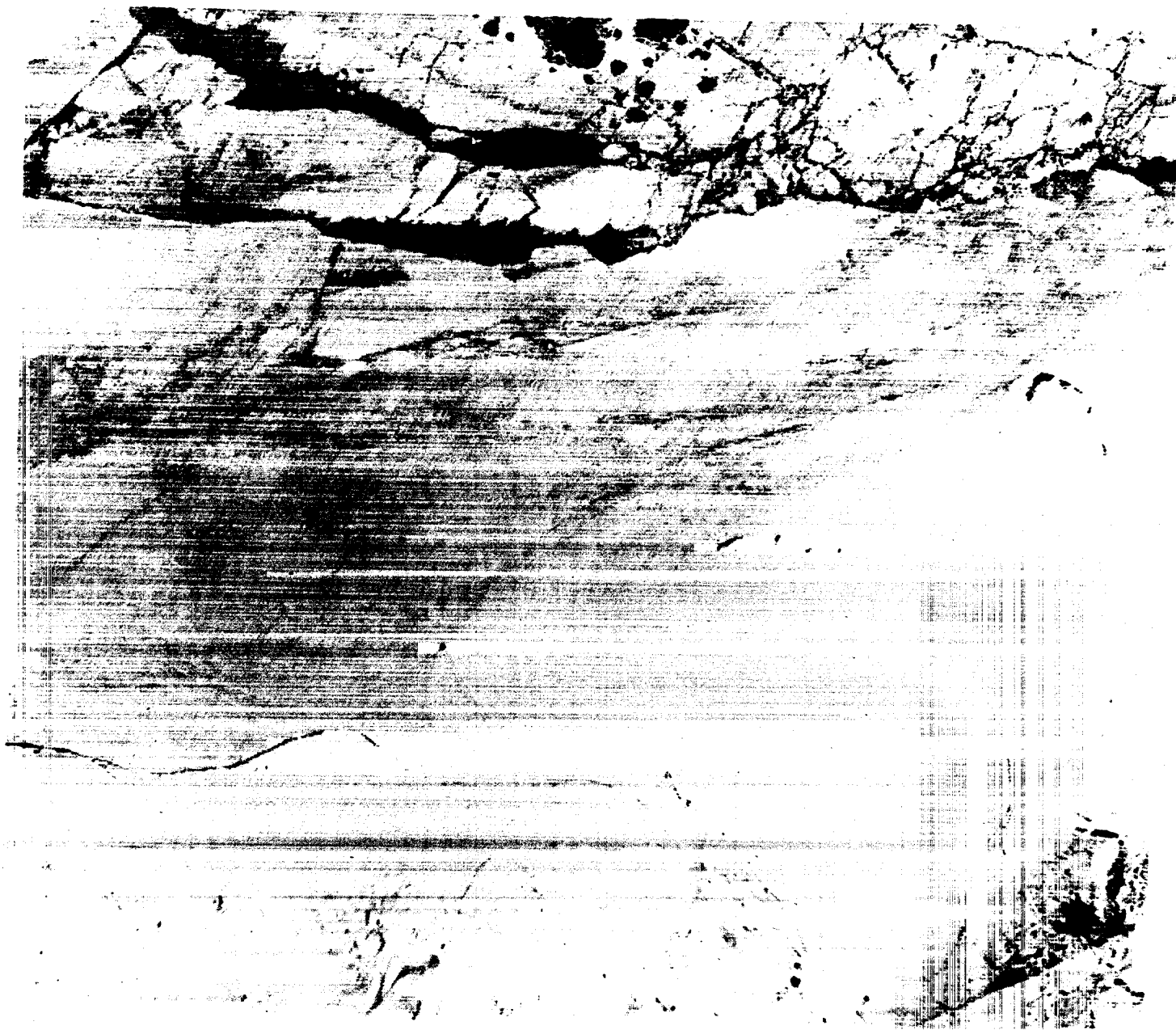


Figure 2. Photo of Seal Island from Site S3, showing low ridges on northeast side of island in region of installation of instrumentation.



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 Seal Island BLog75-125 830323/0025Z



Figure 3. Landsat Quick-Look image of Seal Island, March 23, 1983, showing ice road, and shear zone 16 km north of island.



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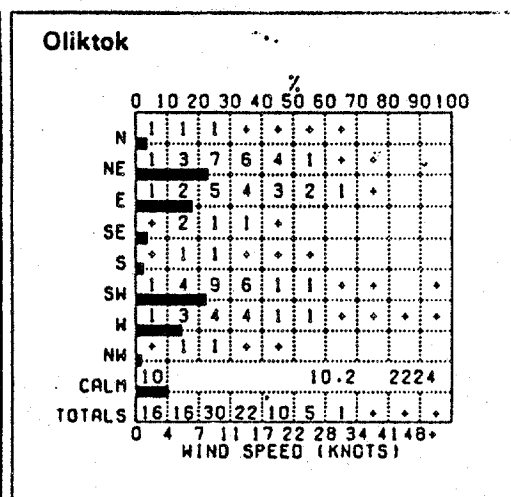
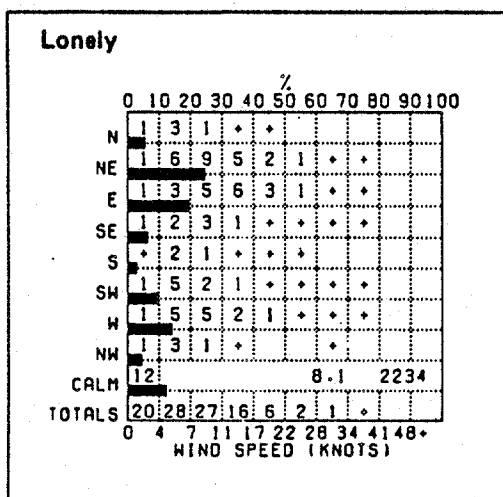
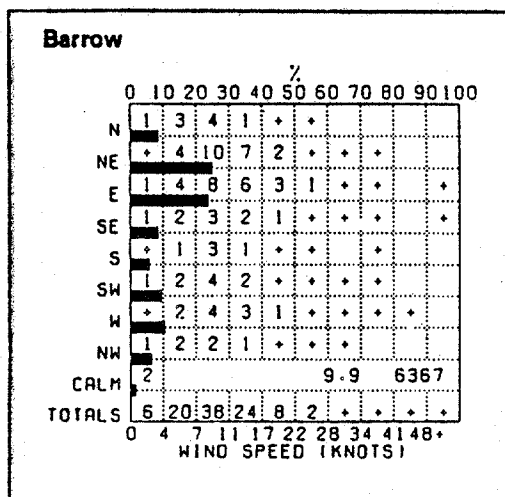


Figure 4. Landsat Quick-Look image of Seal Island, digitally enhanced to show ice ridge extending from barrier islands through Seal Island and to Reindeer Island. Note ice road to island from the southwest.

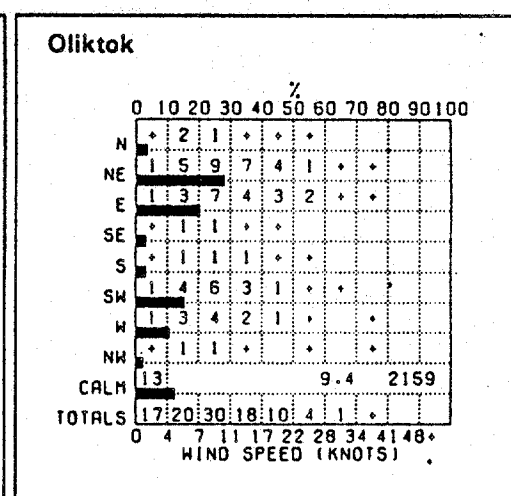
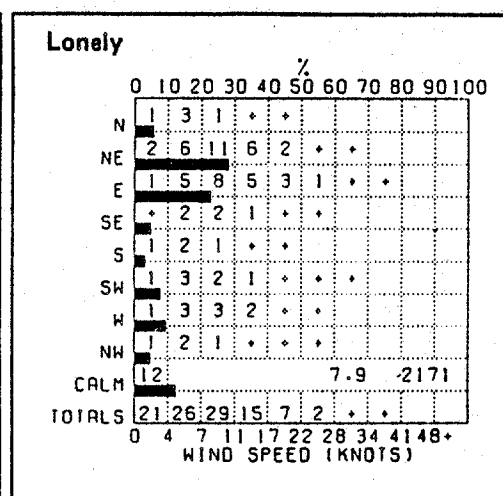
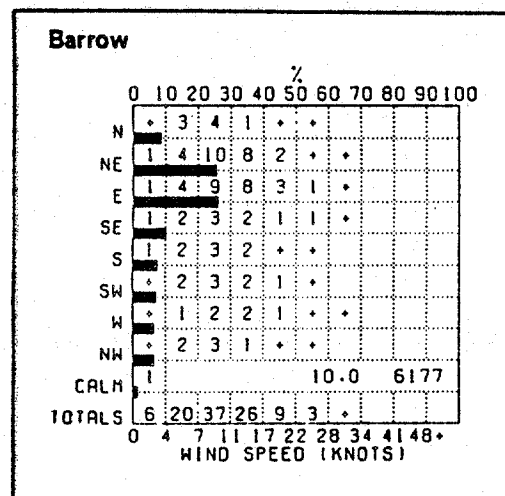
shear zone was some 16 km north of Seal Island shortly after the installation of the instruments.

The dominant direction of the winds on the North Slope for the interval March through May is shown in Figure 5 taken from the Climatic Atlas; the data from Lonely, Oliktok and Barrow are representative of the region. The northeast and east winds, and the southwest and west winds, are the most intense and often cause ice movement. In the case of Seal Island, it was felt that southwest and west winds would only have a limited fetch on the ice sheet due to the adjacent shoreline and barrier island chain, and that the most likely direction for ice movement would be from the northeast, corresponding to the average movement of ice in the Beaufort Gyre. Hence the decision was taken to locate the instrument array northeast of Seal Island, to detect compression and perhaps complex movements expected from that direction.

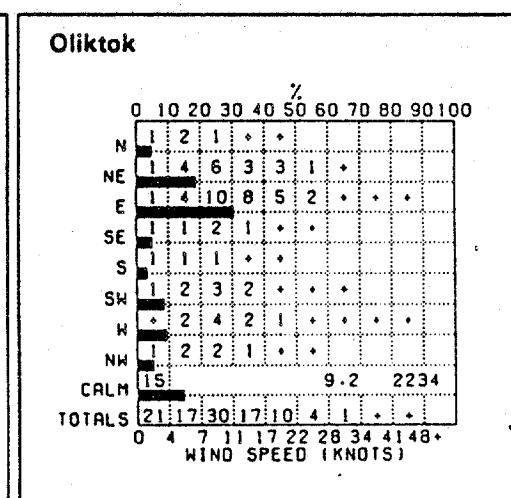
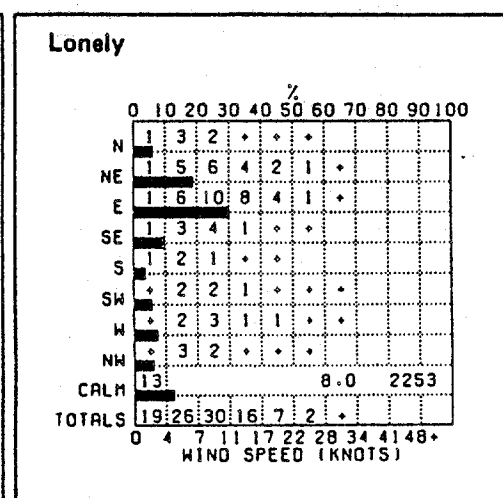
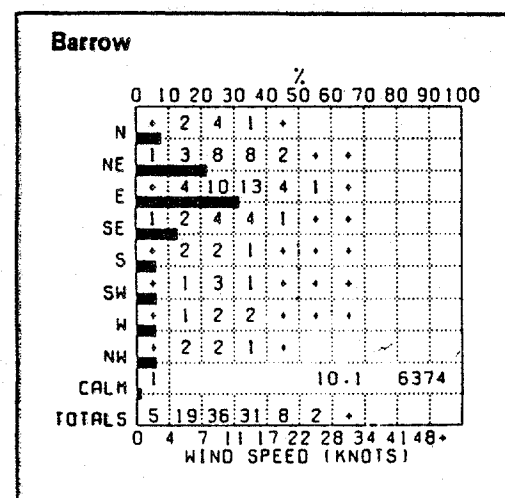
Three separate stations were deployed, as shown in Figure 6. They were deployed along a straight line as shown, with the two satellite stations S1 and S2 each containing an array of three stress sensors, plus wind generation, battery energy storage, and telemetry transmitters. Station S1 contained stress sensors 1, 2, and 3, oriented N-S, E-W, and NW-SE, respectively, utilizing channels 1, 2, and 3. (All directions are with respect to magnetic North). Station S2 contained stress sensors 4, 5, and 6, oriented N-S, E-W, and NW-SE, respectively, utilizing channels 4, 5, and 6. The central station, S3, contained stress sensors 7, 8, and 9, oriented N-S, E-W, and NW-SE, respectively, utilizing channels 7, 8, and 9. All stress sensors were frozen into the ice in a horizontal plane at a depth of 30 cm from the top surface. Each was emplaced by quarrying an intact cubic block from the sea ice sheet with a chain saw, removing a small quantity of sea ice from the bottom edge of the block, just large enough to make a cavity for the uniaxial sensor, and then replacing the original block and the gauge in the ice sheet and freezing it in place by adding fresh water into the chain saw kerfs. The total ice sheet thickness was 180 cm and the water depth was 10.16 meters at the site S3.



March



April



May

Figure 5. Wind direction and windspeed distributions for three weather stations on Alaskan North Slope.

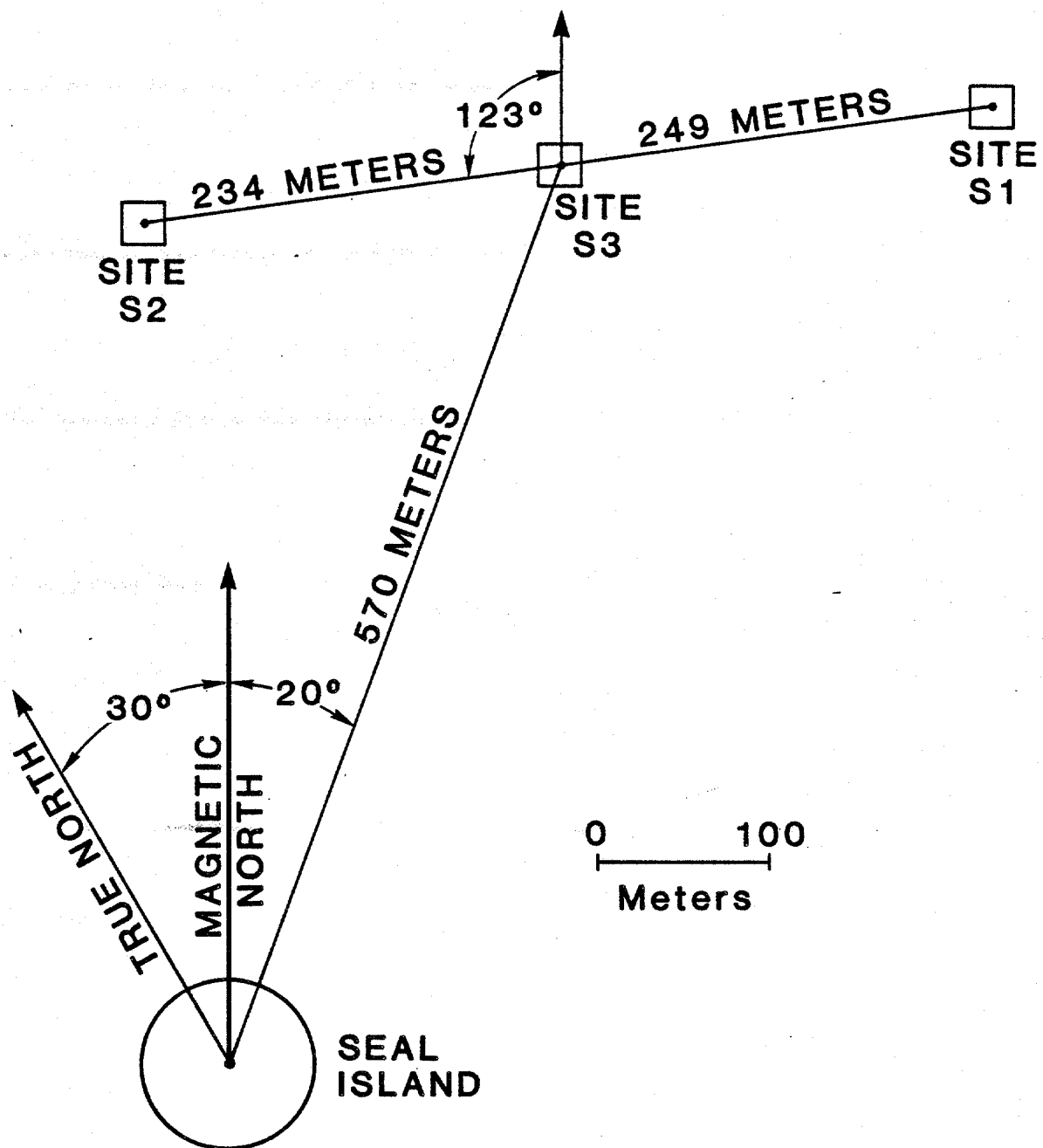


Figure 6. Field station locations.

At the central site, S3, the strain sensors were also installed. These were described in earlier quarterly reports, and each consists essentially of a thin aluminum ring with 3 full strain gauge bridges mounted on it, at 120° angular separation from each other. Three such rings, or nine such gauges, were installed on a single cubical ice block at site S3, and were connected to channels 10-18 of the telemetry system. The block was 30 cm x 30 cm x 30 cm in size.

The salinity profiles at the three sites are shown in the graph (Figure 7). Surface values were 8 ‰ to 12 ‰, with salinities decreasing with depth to about 4 ‰ at 90 cm; the salinity at the 30 cm depth which corresponds to the stress gauge level was uniformly in the range 5.4 ‰ to 6.2 ‰. The reason for the drop in salinity to 4 ‰ at the 15 cm level at site S3 is not known.

The ice movement system was installed with two cables, each wrapped around a pulley which was attached to a digital shaft encoder; one was directly anchored below the site, and the other was anchored in an offset location, thus providing the capability of determining lateral as well as vertical ice movement. These were connected to channels 19 and 20. Windspeed and direction were recorded into channels 21 and 22 from instruments located directly on the roof of the instrument building on Seal Island. A thermistor string was installed in the ice sheet at the central site S3, and Figure 8 illustrates the temperature profiles with ice thickness on four separate occasions during the experiment.

The abrupt transition to -2°C at the 1.2 meter depth for the March 11 data is an indication that the thermistor string was still refreezing into the ice sheet.

The duration of the experiment was 50 days, from March 11 to April 30, 1983. Although it would have been desirable to maintain the system for a longer interval, the abnormal warm weather was causing a deterioration of the ice road leading to Seal Island. Midway in the experiment, it was necessary for Shell to move the instrument building from the island surface location to a new location on the ice sheet adjacent to the island. When the ice road

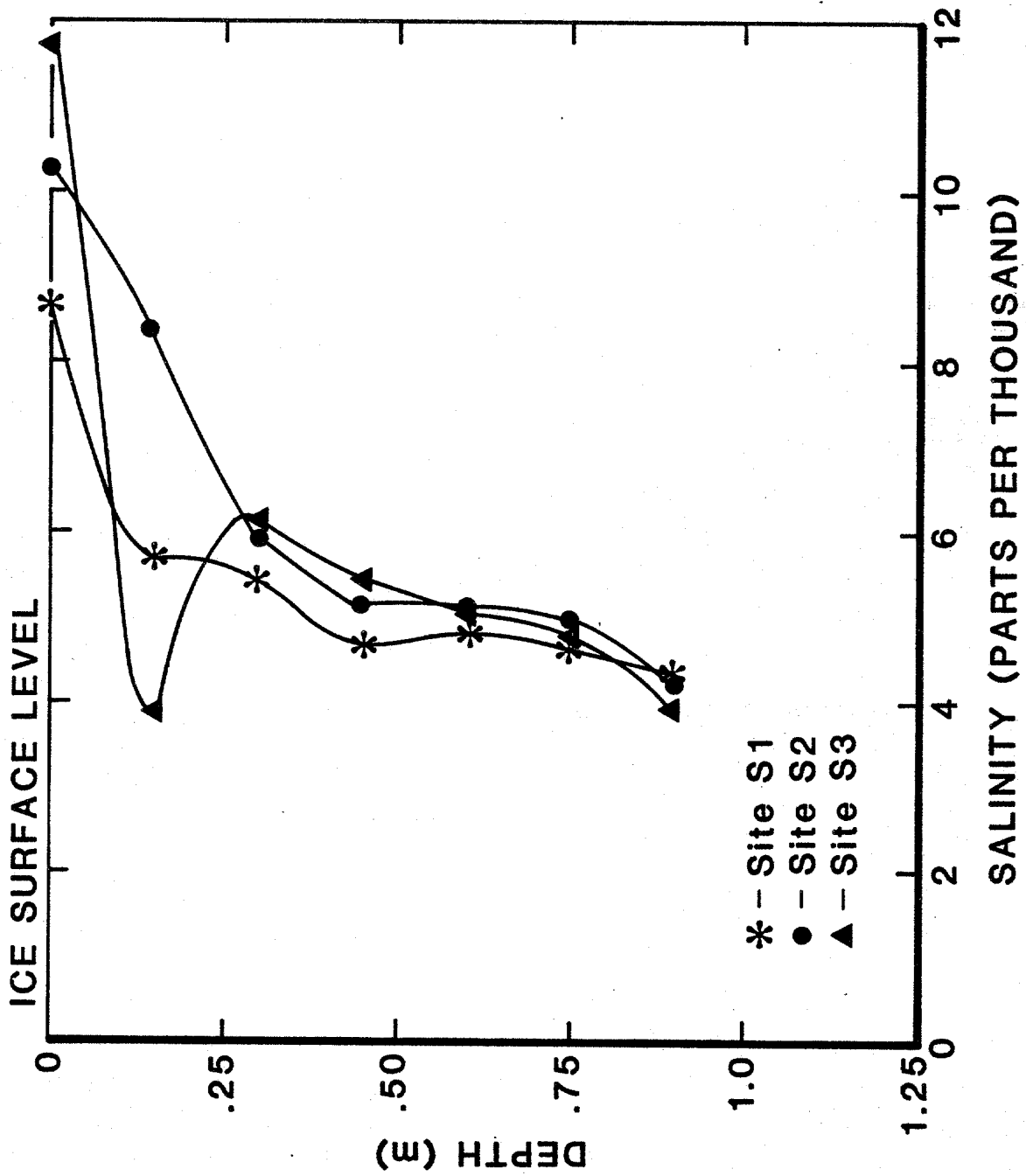


Figure 7. Salinity at sites S1,S2,S3 as a function of depth in the ice sheet. Cores taken April 29, 1983.

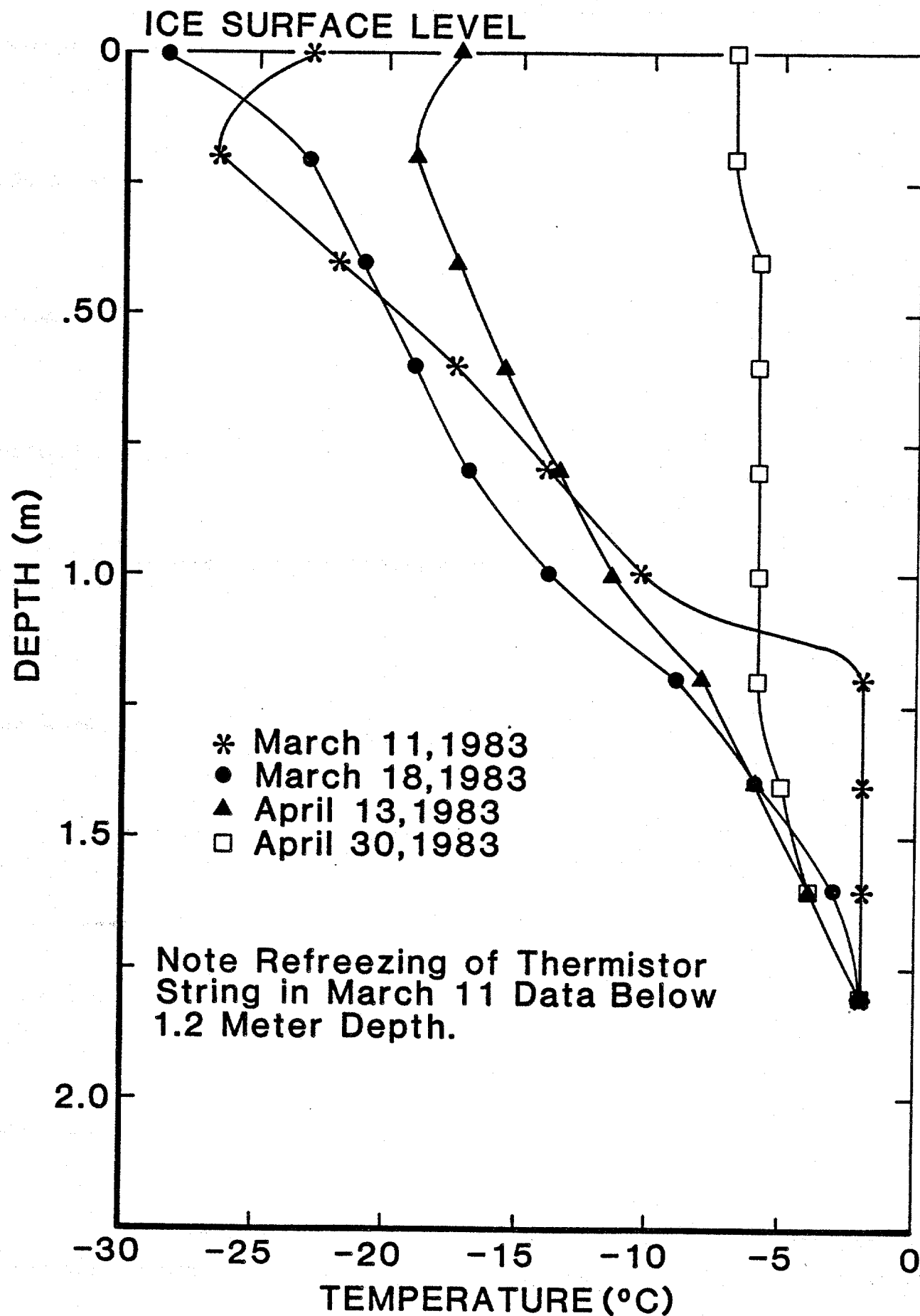


Figure 8. Temperature profiles with depth during field experiment.

began to deteriorate, Shell personnel had to move the instrument building back to shore, and thus the experiment ended with removal of all equipment on April 30, 1983.

The heat generated in each strain gauge bridge (0.3 watts) was beginning to cause brine accumulation at the gauges at this time, implying that decoupling from the ice sheet at the -6°C temperature was imminent.

During the experimental period, the wind velocity was frequently below the 15 knot level, which was needed to operate the wind generators which powered the sites. On-site battery energy storage for up to one week was designed into the system to accommodate this possibility to some degree, but when it became apparent that the recharging of the storage batteries from wind generation was inadequate, gasoline-powered small portable generators were installed at each site. This solved that problem, but required nearly daily service.

An additional consequence of the low wind velocity during the experimental period was that the probability of ice stress buildup was reduced.

An additional instrumental problem experienced at the recording site on the island was the frequency of power outages. To try to ensure that digital data collection was continuous, an uninterruptable power supply was installed in the instrument building, and a service visit every two days was made to collect the digital tape, mount a new tape, and check the system for any obvious problems.

The design by Shell to move the instrument building from the island to an on-ice site near the island (mentioned above) was expected to cause a brief (2-day) outage, but just as the move was almost complete, a high wind and whiteout conditions forced abandonment of Seal Island by all personnel. The high wind condition persisted for several days, during which (unfortunately) the system was not recording data, as the move was incomplete. After the storm, it was possible to again reach the island and

with some additional technical work the move was finished and data collection resumed.

At the end of the field data gathering period, all equipment was removed from the ice sheet and computer analysis of the data tapes was begun. No theoretical work was done during the field program interval.

III. Plans for Next Quarter

Continuation of ice stress gauge calibration, and computerized reduction of the data from the field program, are to take place.

